WDM Network Elements

- A lightpath consists of an optical channel, or wavelength, between two network nodes that is routed through multiple intermediate nodes.

- Intermediate nodes may switch and convert wavelengths.

- Networks may thus be thought of as wavelength-routing networks.

- Lightpaths are set up and taken down as dictated by the users of the network.

- Network consists of optical line terminals (OLTs), optical add/drop links.
OADMs, and OXCs may themselves incorporate optical amplifiers to make up for losses.

As of this writing, OLTs are widely deployed, and OADMNs are deployed to a lesser extent.

OXCs are just beginning to be deployed.

Architecture (Fig7.1) supports a variety of topologies, including ring and mesh topologies.

OLTs multiplex multiple wavelengths into a single fiber and also demultiplex a composite WDM signal into individual wavelengths.
Figure: 7.1
WDM Network Elements

- OLTs are used at either end of a point-to-point link.
- OADMs are used at locations where some fraction of the wavelengths need to be terminated locally and others need to be routed to other destinations.
- Network provides lightpaths to its users, such as SONET boxes and IP Routers.
- Lightpath is carried on a wavelength between its source and destination but may get converted from one wavelength to another along the way.
They are typically deployed in linear or ring topologies.

OXCs perform a similar function but on a much larger scale in terms of number of ports and wavelengths involved, and are deployed in mesh topologies or in order to interconnect multiple rings.

The users (or clients) of this network are connected to the OLTs, OADM s, or OXCs.

Network supports a variety of client types, such as IP routers, ATM switches, and SONET terminals and ADMs.
Each link can support a certain number of wavelengths.

Number of wavelengths that can be supported depends on the component and transmission-imposed limitations.

Several noteworthy features of this architecture:
Wavelength reuse

- Multiple lightpaths in the network can use the same wavelength, as long as they do not overlap on any link.
- This spatial reuse capability allows the network to support a large number of lightpaths using a limited number of wavelengths.
Lightpaths may undergo wavelength conversion along their route.

One such lightpath that uses wavelength $\lambda_2$ on link EX, gets converted to $\lambda_1$ at node X, and uses that wavelength on link X F.

Wavelength conversion can improve the utilization of wavelengths inside the network.

Wavelength conversion is also needed at the boundaries of the network to adapt signals from outside the network into a suitable wavelength for use inside the network.
Transparency

- Transparency refers to the fact that the lightpaths can carry data at a variety of bit rates, protocols, and so forth and can, in effect, be made protocol insensitive.

- This enables the optical layer to support a variety of higher layers concurrently.

- Lightpaths between pairs of SONET terminals, as well as between pairs of IP routers.

- These lightpaths could carry data at different bit rates and protocols.
Circuit switching.

- Lightpaths provided by the optical layer can be set up and taken down upon demand.

- These are analogous to setting up and taking down circuits in circuit-switched networks, except that the rate at which the setup and take-down actions occur is likely to be much slower than, say, the rate for telephone networks with voice circuits.

- In fact, today these lightpaths, once set up, remain in the network for months to years.

- Note that packet switching is not provided within the optical layer.
Circuit switching.

- The technology for optical packet switching is still fairly immature.
- It is left to the higher layer, for example, IP or ATM, to perform any packet-switching functions needed.
Survivability

- Network can be configured such that, in the event of failures, lightpaths can be rerouted over alternative paths automatically.

- This provides a high degree of resilience in the network.
Lightpath topology

- Lightpath topology is the graph consisting of the network nodes, with an edge between two nodes if there is a lightpath between them.

- Lightpath topology thus refers to the topology seen by the higher layers using the optical layer.

- IP network reside above the optical layer - the lightpaths look like links between IP routers.

- The Set of lightpaths can be tailored to meet the traffic requirements of the higher layers.
WDM Network Elements

- Block diagram of an optical line terminal is on next slide.

- The OLT has wavelength multiplexers and demultiplexers and adaptation devices called transponder to transmit over the WDM link and an incoming signal from the WDM link to a suitable signal toward the client.

- Transponders are not needed if the client equipment can directly send and receive signals compatible with the WDM link.

- OLT also terminates a separate optical supervisory channel (OSC) used on the fiber link.
Figure: 7.2
Optical Line Terminals

- OLTs are relatively simple network elements from an architectural perspective.
- They are used at either end of a point-to-point link to multiplex and demultiplex wavelengths.
- Three functional elements inside an OLT: transponders, wavelength multiplexers, and optionally, optical amplifiers.
- A transponder adapts the signal coming in from a client of the optical network into a signal suitable for use inside the optical network.
Optical Line Terminals

- Likewise, in the reverse direction, it adapts the signal from the optical network into a signal suitable for the client.
- Interface between the client and the distance and loss between the client and the transponder.
- The most common interface is the SONET/SDH short-reach (SR).
- Adaptation includes several functions.
- The signal may need to be converted into a wavelength that is suited for use inside the optical network.
Wavelengths generated by the transponder typically conform to standards set by international Telecommunications Union (ITU) in the 1.55μm wavelength window.

- Incoming signal may be a 1.3μm signal.
- Transponder may add additional overhead for purposes of network management.
- It may also add forward error correction (FEC), particularly for signals at 10 Gb/s and higher rates.
- Transponder typically also monitors the bit error rate if the signal at the ingress and egress points in the network.
Optical Line Terminals

- Adaptation is typically done through an optical-to-electrical-to-optical (O/E/O) conversion.
- In some situations, it is possible to have the adaptation enabled only in the incoming direction and have the ITU wavelength in the other direction directly sent to the client equipment.
- In some other situations, we can avoid the use of transponders by having the adaptation function performed inside the client equipment that is using the optical network, such as a SONET network element.
Optical Line Terminals

- This reduces the cost and results in a more compact and power-efficient solution.
- WDM interface specification is proprietary to each WDM vendor, and there are no standards.
- Transponders typically constitute the bulk of the cost, footprint, and power consumption in an OLT.
- Therefore reducing the number of transponders helps minimize both the cost and the size of the equipment deployed.
- The signal coming out of a transponder is multiplexed with other signals at different wavelengths using a wavelength multiplexer onto a fiber.
Optical Line Terminals

- Fiber Bragg gratings, can be used for this purpose.
- In addition, an optical amplifier may be used to boost the signal power if needed.
- In the other direction, the WDM signal is amplified again, if needed, before it is sent through a demultiplexer that extracts the individual wavelengths.
- These wavelengths are again terminated in a transponder (if present) or directly in the client equipment.
- Finally, the OLT also terminates an optical supervisory channel (OSC).
Optical Line Terminals

- OSC is carried on a separate wavelength, different from the wavelengths carrying the actual traffic.
- It is used to monitor the performance of amplifiers along the link as well as for variety of other management functions.
- In figure 7.3, Amplifier uses multiple erbium gain stages and optionally includes dispersion compensators and OADMs between the gain stages.
- OSC is filtered at the input and terminated, and added back at the output.
Figure: 7.3
Optical Line Amplifiers

- Optical line amplifiers are deployed in the middle of the optical fiber link at periodic intervals, typically 80-120 km.
- Basic elements is an erbium-doped fiber gain block.
- Typical amplifiers use two or more gain blocks in cascade, with so-called midstage access.
- This feature allows some lossy elements to be placed between the two amplifier stages without significantly impacting the overall noise figure of the amplifier.
These elements include dispersion compensators to compensate for the chromatic dispersion accumulated along the link, and also the OADMs.

The amplifiers also include automatic gain control and built-in performance monitoring of the signal.

Optical supervisory channel is filtered at the input and terminated, and added back at the output.

In a system using C-and L-bands, the bands are separated at the input to the amplifier and separate EDFAs are used for each band.
Optical Add/Drop Multiplexers

Optical add/drop multiplexers (OADMs) provide a cost-effective means for handling passthrough traffic in both metro and long-haul networks.

- OADMs may be used at amplifier sites in long-haul networks but can also be used as stand-alone network elements, particularly in metro networks.
- In figure 7.4, A three node linear network example to illustrate the role of optical add/drop multiplexers.
- Three wavelengths are needed between nodes A and C, and one wavelength each between nodes A and B and between nodes B and C.
  7.4(a) A solution using point-to-point WDM systems.
  7.4(b) A solution using an optical add/drop multiplexer at node B.
Figure: 7.4
Optical Add/Drop Multiplexers

To understand the benefits of OADMs, consider a network between three nodes, say, A, B, and C, with IP routers located at nodes A, B, C, and A and C.

Based on the network topology, traffic between A and C passes through node B. For simplicity, we will assume full-duplex links and full-duplex connections.

This is the case for most networks today.

Actually consists of a pair of fibers carrying traffic in opposite directions.
Suppose the traffic requirement is as follows: one wavelength between A and C.

Now suppose we deploy point-to-point WDM systems to support this traffic demand.

Two point-to-point systems are deployed, one between A and B and the other between B and C.

Each point-to-point system uses an OLT at each of the link.

OLT includes multiplexers, demultiplexers, and transponders.

These transponders constitute a significant portion of the system cost.
Consider what is needed at node B.

- Node B has two OLTs.
- Each OLT terminates four wavelengths and therefore requires four transponders.
- However, only one out of those four wavelengths is destined for node B.
- Remaining transponders are used to support the passthrough traffic between A and C.
- These transponders are hooked back to back to provide this function.
- Therefore, six out of the eight transponders at node B are used to handle passthrough traffic a very expensive proposition.
Instead of deploying point-to-point WDM systems, we now deploy a wavelength-routing network.

Network uses an OLT at nodes A and C and an OADM at node B.

OADM drops one of the four wavelengths, which is then terminated in transponders.

Remaining three wavelengths are passed through in the optical domain using relatively simple filtering techniques, without being terminated in transponders.
Net effect is that only two transponders are needed at node B, instead of the eight transponders required for the solution shown in Figure 7.4(a).

Represents a significant cost reduction.

In typical carrier networks, the fraction of traffic that is to be passed through a node without requiring termination can be quite large at many of the network nodes.

OADMs perform a crucial function of passing through this traffic in a cost-effective manner.

Physical layer engineering for networks is considerably more complex than that for point-to-point systems.
Optical Add/Drop Multiplexers

- OADMs are rather inflexible.
- They are, for the most part, static elements and do not allow in service selection under software control of what channels are dropped and passed through.
- Most practical OADMs use either fiber Bragg gratings, dielectric thin-film filters, or arrayed waveguide gratings.